Laser Triangulation Provides Essential Metrology and Defect Inspection for Microbumps in 3DIC Manufacturing

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ABSTRACT

Continuous miniaturization and the advent of TSV packages are pushing solder bump sizes smaller and smaller. Micro bumps and pillar bumps are the main bump geometries leading this advance. 3D packages are expected to require hundreds of thousands of bumps at pitch values down to 10μm and lower. The small bump size, small pitch and high number of bumps are challenging inspection technologies, requiring inspection at higher accuracies and higher throughput. Laser triangulation has been used successfully to inspect bumps of many different shapes and sizes over the past several years.

This study will analyze the performance and extendibility of laser triangulation technology in 3D inspection of micro solder and pillar bumps. The laser triangulation technique examined in this study is a line scan laser with the ability to collect hundreds of 3D data points along one scan line in a fraction of a second. These data points can then be used to build a 3D model of the top of the bump and surface of the wafer for local height inspection. The specific challenge with smaller bumps is the ability to have enough data points on top of the bump, as the surface area decreases. Results of an application study of a 10μm bump height as well as a 20μm pitch bump are reviewed.

INTRODUCTION

The speed and accuracy of laser triangulation have made it the dominant technology for three dimensional characterization of solder bumps used in conventional packaging techniques such as flip chips. Three dimensional integrated circuits (3DIC) use through silicon vias (TSV) to provide the necessary connections among vertically stacked chips. In these applications the bumps are typically smaller, more closely spaced and far more numerous. This paper evaluates the ability of laser triangulation to provide 3D bump metrology with the precision and speed required to optimize and control bump process as they move forward into high volume production.

BUMP EVALUATION

Bumps come in many different sizes and shapes. Microbumps, traditional solder bumps with diameters and heights as small as a few micrometers, and pillar bumps with or without solder cap, are the main bump geometries used in 3DIC interconnects. The number of bumps used in 3DIC schemes has grown explosively, with current roadmaps calling for as many as one million bumps per die and 60 million bumps per wafer.

Existing metrology tools are significantly challenged to provide the speed and precision required to maintain sufficiently narrow process windows and ensure high yields. Bump heights of only a few micrometers require submicron 3D measurement precision. Diameters and pitches of 20 micrometers or less pose equally daunting 2D measurement challenges. The instrument must be capable of measuring a variety of materials, including copper, nickel, and solders of varying compositions. The large number of bumps places a heavy load on data storage and processing facilities. Finally, the measurement system must strike an optimal balance between precision and throughput if it is to be utilized in production.

The studies described here were performed using a Wafer Scanner™ 3880 system from Rudolph Technologies equipped with the new ultra high resolution detector. The first study evaluated repeatability and throughput on solder microbumps nominally 20 micrometers in diameter and 8 micrometers tall. The study examined 300 mm wafers, each containing approximately three million bumps. The study evaluates the system's ability to measure bump height, coplanarity and diameter, and to detect defects in bumps and on the surrounding wafer surface.

The inspection system uses laser triangulation for 3D measurements of bump height and coplanarity (figure 1). A laser, incident on the wafer surface at an angle of 45 degrees and focused to a spot size of 5 micrometers, scans a line over 1 mm in length on the wafer surface while the wafer is transported in a direction perpendicular to the scanned line. A lens collects the reflected/scattered laser light and focuses it on a position sensitive detector. Changes in the location of the collected light on the detector provide height measurements with a resolution of 54 nm. The system has a 28µm depth of focus and an 8 MHz data acquisition rate. The combination of high scanning rate and wide scan path permit 100% 3D scanning of a 300 mm wafer in 23 minutes, a throughput of nearly 2.5 wafers per hour.

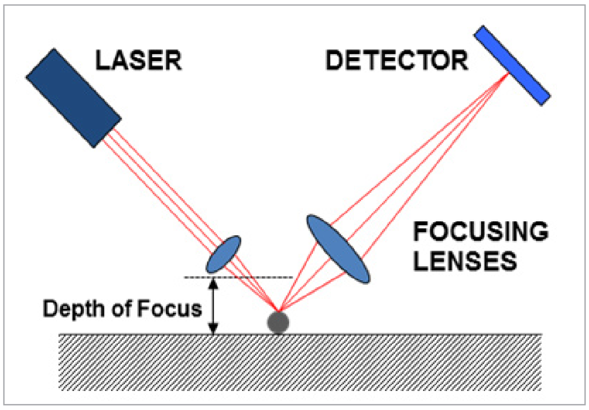


Figure 1 *- Laser triangulation uses a finely focused laser and a position sensitive detector to measure feature height*

During operation the system scans the entire wafer surface in swath widths of over 1 mm, simultaneously acquiring height data from both the tops of the bumps and the surrounding wafer surface. The spacing of the data points can be varied to optimize efficiency on bumps of various sizes. The system can display 3D data points collected on individual bumps (figure 2) as well as calculating various bump, die and wafer level results. Using data from the top of the bump and the immediately adjacent wafer surface to calculate bump height improves the accuracy and repeatability of the measurements.

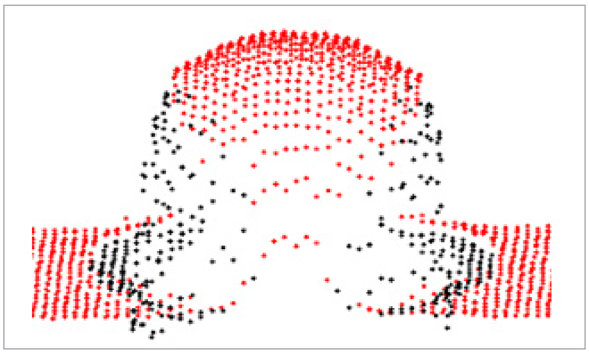


Figure 2 *- Numerous data points acquired from the top of the bump and the surrounding wafer surface permit fast, precise measurements as well as reconstruction of 3D images of individual bumps*

A unique staggered scan technique further enhances the repeatability of bump height measurements. Staggering the scan increases the pitch in the direction of the line scan and reduces the pitch in the direction of the wafer movement, effectively spreading the data points more evenly over the wafer surface with no penalty in throughput. Figure 3 demonstrates a nearly fivefold improvement in bump by bump repeatability (from 0.575µm to 0.12µm) using the staggered scan technique.

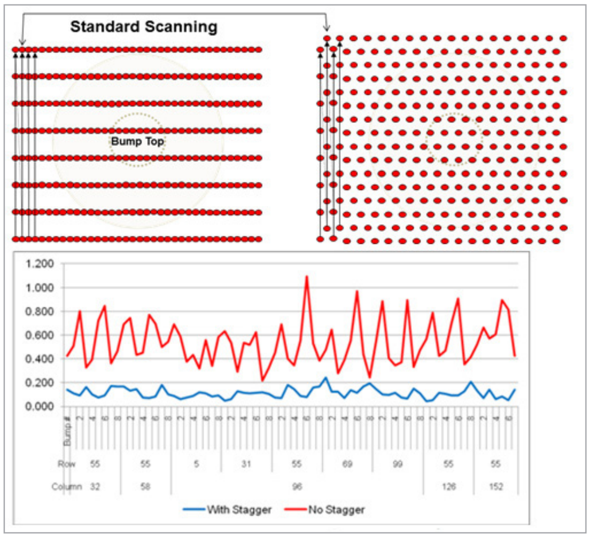


Figure 3 *- Staggered scanning improves bump height measurement precision by almost 5X*

Figure 4 shows the result of a full wafer measurement of individual bump heights. In addition to full wafer results, the system can display profiles of individual bumps (figure 5). Notice the multiplicity of data points from bump, trace and wafer surface, essential to ensure accurate measurements. In the average bump height wafer map shown in figure 6, bump heights are averaged over each die. This map shows a definite trend from upper right to lower left across the wafer, indicating a need for corrective action and, possibly, an opportunity for yield improvement. The die coplanarity map in figure 7 shows the difference between the highest and lowest bump height with respect to a best fit plane for each die. This plot is more sensitive to individual variations in bump height and the pattern appears more random, though poorer coplanarity values do seem to be distributed more heavily toward the edges, particularly the right edge.

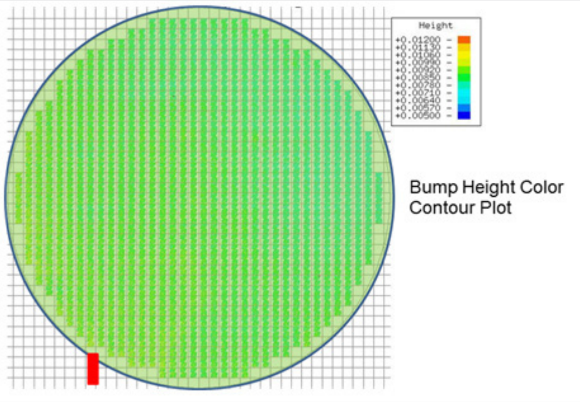


Figure 4 *- Full wafer bump height map displays color coded height of individual bumps*

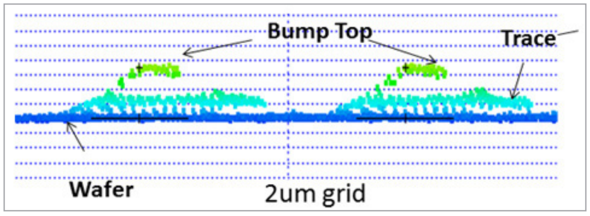
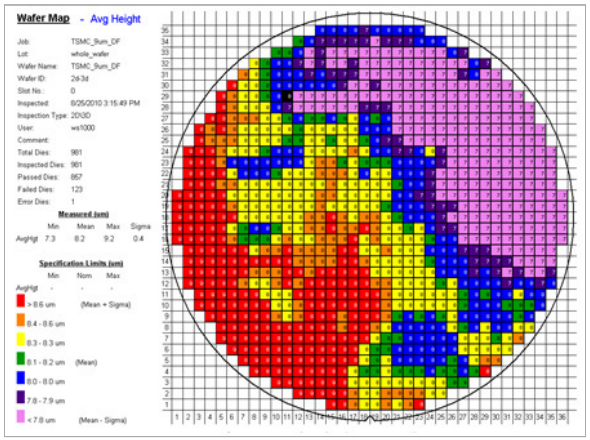


Figure 5 *- 3D bump profile shows color coded data points that comprise each bump measurement. Numerous data points are available for the wafer surface (blue) the trace (cyan) and the bump top (green).*



Wafer Map - Avg Height

Job: TSMC_9um_DF
Lot: whole_wafer
Wafer Name: TSMC_9um_DF
Wafer ID: 2d-3d
Slot No.: 0
Inspected: 8/25/2010 3:15:49 PM
Inspection Type: 2D\3D
User: ws1000
Comment:
Total Dies: 981
Inspected Dies: 981
Passed Dies: 857
Failed Dies: 123
Error Dies: 1

Measured (um)

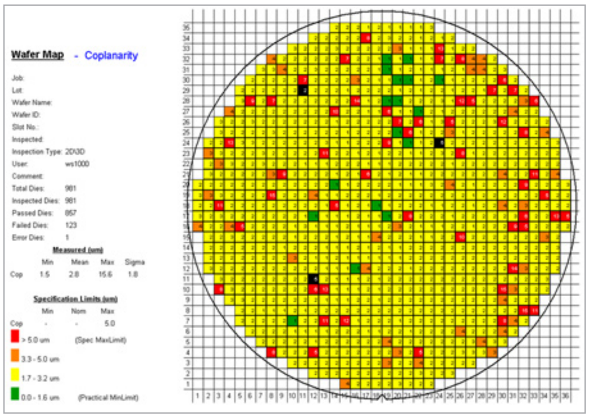
	Min	Mean	Max	Sigma
AvgHgt	7.3	8.2	9.2	0.4

Specification Limits (um)

	Min	Nom	Max
AvgHgt	-	-	-

🟥 > 8.6 um (Mean + Sigma)
🟧 8.4 - 8.6 um
🟨 8.3 - 8.3 um
🟩 8.1 - 8.2 um (Mean)
🟦 8.0 - 8.0 um
🟪 7.8 - 7.9 um
▨ < 7.8 um (Mean - Sigma)

Figure 6 *- Average bump height wafer map displays the average bump height in each die across the full wafer. In this example there is an apparent trend to greater bump height from upper left to lower right, suggesting a need for corrective action*



Wafer Map - Coplanarity

Job:
Lot:
Wafer Name:
Wafer ID:
Slot No.:
Inspected:
Inspection Type: 2D\3D
User: ws1000
Comment:
Total Dies: 981
Inspected Dies: 981
Passed Dies: 857
Failed Dies: 123
Error Dies: 1

Measured (um)

	Min	Mean	Max	Sigma
Cop	1.5	2.8	15.6	1.8

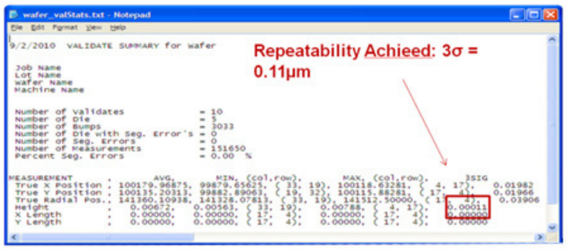
Specification Limits (um)

	Min	Nom	Max
Cop	-	-	5.0

🟥 > 5.0 um (Spec MaxLimit)
🟧 3.3 - 5.0 um
🟨 1.7 - 3.2 um
🟩 0.0 - 1.6 um (Practical MinLimit)

Figure 7 *- A die coplanarity map displays the difference between the highest and lowest bump height with respect to a best fit plane for each die across the wafer. This example seems to show a tendency for poorer coplanarity values toward the edges of the wafer, particularly the right edge.*

Finally, figure 8 shows the results of a repeatability analysis of bump height measurements. Five die from various locations on the wafer, each containing over 3,000 bumps, were sampled for a combined total of over 15,000 bumps. The measurement was repeated ten times and results for each bump evaluated over the ten measurements. Three sigma repeatability was calculated to be 0.11µm.



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9/2/2010  VALIDATE SUMMARY for wafer

 Job Name
 Lot Name
 Wafer Name
 Machine Name


 Number of Validates               = 10
 Number of Die                     = 5
 Number of Bumps                   = 3033
 Number of Die with Seg. Error's   = 0
 Number of Seg. Errors             = 0
 Number of Measurements            = 151650
 Percent Seg. Errors               = 0.00  %

MEASUREMENT          ,        AVG,          MIN, (col,row),          MAX, (col,row),       3SIG
 True X Position     , 100179.96875,  99879.65625, ( 33, 19), 100118.63281, (  4, 17),     0.01982
 True Y Position     , 100135.20313,  99882.89063, ( 19, 32), 100115.88281, ( 17,  4),     0.01966
 True Radial Pos.    , 141360.10938, 141328.07813, ( 33, 19), 141512.50000, ( 17,  4),     0.03906
 Height              ,      0.00672,      0.00563, ( 33, 19),      0.00788, (  4, 17),    0.00011
 X Length            ,      0.00000,      0.00000, ( 17,  4),      0.00000, ( 17,  4),    0.00000
 Y Length            ,      0.00000,      0.00000, ( 17,  4),      0.00000, ( 17,  4),    0.00000
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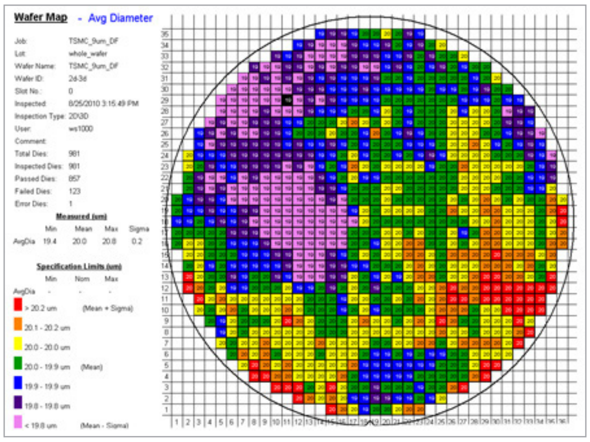
Figure 8 *- This bump height repeatability evaluation included ten measurements of over 3,000 bumps on each of five die to calculate a 3 sigma repeatability of 0.11 micrometers.*

The inspection system also includes a line scan camera for image-based 2D measurements (such as bump diameter) and defect detection. Figure 9 shows average bump diameter for each die across the full wafer. Again a trend is apparent with smaller bumps at lower right and larger bumps at upper left. Figure 10 presents a selection of bump defects detected on the wafer. Figure 11 demonstrates the system's ability to directly correlate individual defects to measurement data. In this example, the bump identified as defective in the 2D inspection also displayed excessive height in the 3D measurement.



Job: TSMC_9um_DF
Lot: whole_wafer
Wafer Name: TSMC_9um_DF
Wafer ID: 2d-3d
Slot No.: 0
Inspected: 8/25/2010 3:15:49 PM
Inspection Type: 2D\3D
User: ws1000
Comment:
Total Dies: 981
Inspected Dies: 981
Passed Dies: 857
Failed Dies: 123
Error Dies: 1

Measured (um)

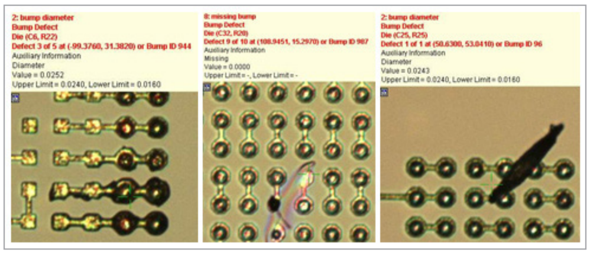
	Min	Mean	Max	Sigma
AvgDia	19.4	20.0	20.8	0.2

Specification Limits (um)

	Min	Nom	Max
AvgDia	-	-	-

🟥 > 20.2 um (Mean + Sigma)
🟧 20.1 - 20.2 um
🟨 20.0 - 20.0 um
🟩 20.0 - 19.9 um (Mean)
🟦 19.9 - 19.9 um
🟪 19.8 - 19.8 um
🟪 < 19.8 um (Mean - Sigma)

Figure 9 - 2D measurements, such as this one displaying average bump diameter for each die cross the full wafer, are performed in a separate scan using a line scan camera.

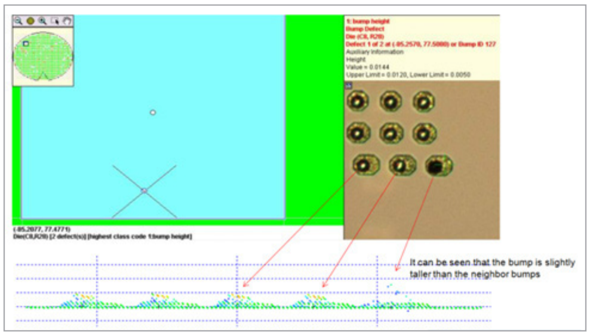


2: bump diameter
Bump Defect
Die (C6, R22)
Defect 3 of 5 at (-99.3760, 31.3820) or Bump ID 944
Auxiliary Information
Diameter
Value = 0.0252
Upper Limit = 0.0240, Lower Limit = 0.0160

8: missing bump
Bump Defect
Die (C32, R20)
Defect 9 of 10 at (108.9451, 15.2970) or Bump ID 987
Auxiliary Information
Missing
Value = 0.0000
Upper Limit = -, Lower Limit = -

2: bump diameter
Bump Defect
Die (C25, R25)
Defect 1 of 1 at (50.6300, 53.0410) or Bump ID 96
Auxiliary Information
Diameter
Value = 0.0243
Upper Limit = 0.0240, Lower Limit = 0.0160

Figure 10 - Image-based inspection detects defects such as contamination, corrosion, and missing bumps, as well as ensuring that two dimensional characteristics, such as diameter and position, fall within specifications.



1: bump height
Bump Defect
Die (C8, R20)
Defect 1 of 2 at (-85.2570, 77.5080) or Bump ID 127
Auxiliary Information
Height
Value = 0.0144
Upper Limit = 0.0120, Lower Limit = 0.0050

(-85.2077, 77.4771)
Die(C8,R20) [2 defect(s)] [highest class code 1:bump height]

It can be seen that the bump is slightly taller than the neighbor bumps

Figure 11 - From the wafer map the user can zoom in to examine individual defects and correlate the defect image directly with 2D and 3D measurements.

The second phase of this evaluation looked at the system's ability to measure the height of closely spaced (small pitch) bumps. Because of the 45 degree incidence angle of the laser, the bump may shadow a portion of the wafer surface adjacent to the bump on the side opposite the laser, and the next bump may prevent reflected laser light from reaching the detector. The degree of shadowing depends on the shape and height of the bumps, but may well be enough to prevent the acquisition of any data points between tall, closely spaced bumps (Figure 12). The effect is evident in figure 13 where areas from which data are not available are shown in white. However, relevant wafer surface data remain available for all bumps from areas to the side of the bumps (perpendicular to the direction of the laser) providing a valid basis for bump height calculations.

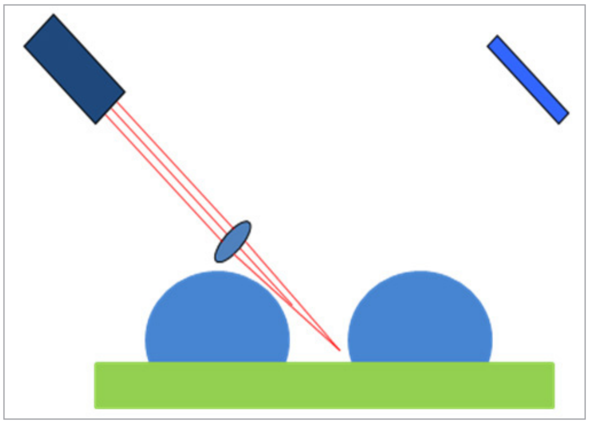


Figure 12 - Decreasing pitch and increasing bump height lead to shadowing that prevents the acquisition of data points between bumps in the direction of the laser

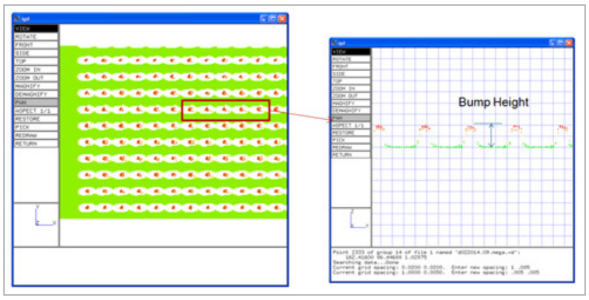


Figure 13 - The shadowing effect is apparent in this scan where areas without data are represented in white (left). Accurate bump height measurements are still possible using wafer surface data points between the rows (right).

CONCLUSION

Laser triangulation provides fast, accurate and repeatable 3D measurement of microbumps. In combination with camera-based 2D measurements it provides a complete solution for bump metrology and defect inspection. A precision of 0.11μm is achieved for the 8 μm bump heights measured in the study. The multiplicity of data points acquired on the top of each bump by the ultra high resolution detector ensures measurement repeatability. The system can also measure heights of closely spaced bumps where shadowing prevents the acquisition of data in some areas between bumps. The 8 MHz sampling rate and over 1 mm scan width provide production worthy throughput without sacrificing accuracy and repeatability. With bump sizes and pitches sure to decrease and bump numbers headed for tens of millions per wafer, the ability to tightly control bump processes and detect bump defects will surely become essential to the success of 3DIC technologies and the profitability of 3DIC manufacturers.